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PHYSICS.—*The theory of the stiffness of elastic systems.*[1] By M. D. HERSEY, Bureau of Standards. (Communicated by Louis A. Fischer.)

Introduction. The stiffness of a body, or of a system of bodies, we define as the ratio of the force[2] applied to the deflection produced. It is not, of course, an intrinsic property of the body or system itself, but depends also on the manner of applying the force, and on the point whose displacement is to be observed. The stiffness of a body under given conditions is, however, its most important elastic property. The conception is useful in dealing with the vibrations of structures; the yielding of the supports of instruments; the design of aneroid barometers, pressure gages, torsion meters,[2] etc.; and with springs wherever they occur. But the tendency in elasticity, as in other branches of physics today, appears to be to desert the obvious and to court the remote. Instead of treating stiffness directly, writers on elasticity make a detour, first determining the strain distribution throughout the interior of the body; a procedure which, besides being laborious, limits the validity of the result to certain rather simple geometrical shapes. This detailed analysis is indispensable for some purposes but not for all, as the theorems presented in this paper will show. All of these theorems have

[1] This work was done at the Jefferson Physical Laboratory, Harvard University. It is expected that it will be published in more detail upon the completion of a series of experiments on the subject recently begun at the Bureau of Standards.

[2] The reader interested in galvanometer suspensions or other torsion problems can readily modify the formulas of the present paper so as to make them apply to couples instead of to translational forces.

applications to the aneroid barometer, which will be treated elsewhere, but their applicability is not confined to that particular elastic system.

The stiffness of coupled systems.[3] Having given the individual stiffness s_a and s_b of two systems A and B (ordinarily but not necessarily single bodies) which are coupled together, let it be required to find the stiffness, S, of the coupled system. It is understood that s_a and s_b refer to forces and displacements at the coupling, while S refers to a displacement at the coupling, but to a force applied anywhere. The desired general relation is found to be[4]

$$S = \lambda(s_a + s_b) \tag{1}$$

where λ is a dimensionless characteristic of the component to which the external force is applied, and denotes the ratio of its stiffness with respect to that force, to its stiffness (s_a or s_b) with respect to a force at the coupling. If the external force is itself applied at the coupling, $\lambda = 1$, and the stiffness of the coupled system equals the sum of the stiffnesses of the components. This can be shown by a simple experiment. Make a rigid frame about a foot square and cut off two five-inch lengths of the same helical spring. Fasten the two springs, respectively, each by one end, to two opposite sides of the frame, in

[3] In treating coupled systems, the displacements are assumed small. This restriction does not apply to the subsequent discussion of a single body.

[4] Let x be the displacement of a reference mark at the fraction r of the distance along the coupling piece from A toward B, while x_a and x_b are the respective displacements necessary for coupling the two members, t being the tension in the coupling, and F the particular external force, applied to A, with respect to which we seek the stiffness of the coupled system, S. Then, by definition, $S = \frac{F}{x}$, while the conditions of equilibrium and constraint are expressed by the four equations

$$x = (1-r)\,x_a - r\,x_b \qquad x_a + x_b = \text{constant}$$

$$x_a = \frac{F}{\lambda s_a} + \frac{t}{s_a} + \text{const.} \qquad x_b = \frac{t}{s_b} + \text{const.}$$

in which the forces and displacements are interpreted vectorially. Eliminating the three quantities x_a, x_b, and t gives

$$F = \lambda(s_a + s_b)x + K$$

in which K denotes a term involving r, s_a, and s_b, but obviously vanishing if the system is so adjusted that $x = 0$ when $F = 0$. Dividing through by x now gives the result (1).

such a way that the springs fail to meet by about an inch. Holding the frame vertical, hang a weight to the free end of the upper spring, and note the deflection. Then couple the two springs together. The same weight will now cause but half that deflection. The experiment can readily be extended to show the effect of using springs of unequal stiffnesses, or of weights hung not at the coupling.

Influence of temperature and elastic after-effect on coupled systems.[5] Differentiating (1) gives for the fractional change in the stiffness of the coupled system, in terms of the fractional changes in the stiffnesses of the components, due to any cause whatever,

$$\frac{dS}{S} = \eta \frac{ds_a}{s_a} + (1 - \eta) \frac{ds_b}{s_b} \tag{2}$$

in which the dimensionless characteristic η denotes $\frac{s_a}{s_a + s_b}$, and depends evidently on the two components but not on λ, and, therefore, not on the manner of applying the external force. The changes ds_a and ds_b may equally well be interpreted as temperature effects, or elastic after-effects. In either case (2) shows that the relative contributions of the two components are fixed by the single factor η and are proportional to the respective stiffnesses. We therefore pass to the consideration of the stiffness of a single body.

General expression for the stiffness of a body. The treatment of non-homogeneous or anisotropic bodies will be simplified by the conception of *generalized shape.* Two bodies may be said to have the same generalized shape when not simply linear magnitudes, but all physical quantities associated with points in the bodies, are similarly distributed in the two bodies; that is, distributed so that the ratio of the two magnitudes of any one such quantity is the same at all pairs of corresponding points. Thus two pieces of rolled sheet metal of different sizes and materials have the same generalized shape if they have been cut out to the same geometrical shape, similarly oriented with respect to the direction of rolling, and if the rolling has pro-

[5] The displacement due to temperature or to elastic after-effect at constant load is assumed so small that, in differentiating (1), λ may be regarded as constant.

duced in each case the same relative variation of elastic constants over the cross section. When any elastic constant of a series of bodies is represented by a single symbol, it is to be understood that this refers to its mean value, or to its value at a particular point and in a particular direction, and that all bodies in the series are of the same generalized shape. Finally, if the bodies in such a series, although not violating Hooke's law at any point within the material, are so greatly deformed that there is no longer a direct proportionality between load and deflection, it is to be understood that the bodies remain geometrically similar to each other while being deformed.

With this understanding, it may be shown by dimensional reasoning that the stiffness of any of a series of perfectly elastic bodies of different sizes or materials but of the same generalized shape is given by

$$S = LE \cdot \phi(\sigma) = L\mu \cdot \psi(\sigma) = L \cdot f(E,\mu) \tag{3}$$

in which L denotes any chosen linear dimension, E Young's modulus, μ the rigidity (i.e., shear modulus) and σ Poisson's ratio. The functions ϕ, ψ, and f are to be found, if they need to be known at all, by detailed calculations employing the conventional theory of elasticity, or by model experiments.

Thus to find $\varphi\ (\sigma)$ we need only plot observed values of $\frac{S}{LE}$ against known values of σ for a series of models of the same generalized shape, but having any convenient values of L, E, and σ covering the desired range along the σ scale. In practice, the method of model experiments will be limited by the difficulty of procuring materials, which, if intended to be isotropic, are sufficiently so; or which, if intended to be anisotropic, are sufficiently similar in internal structure sensibly to satisfy the requirement of having the same generalized shape.

The change in stiffness with temperature, and criteria for compensation. Differentiating (3) gives, for the fractional change in stiffness with temperature, θ,

$$\frac{1}{S}\frac{dS}{d\theta} = A\alpha + B\beta + \gamma \tag{4}$$

in which

$$\left.\begin{aligned} A &\equiv \frac{1}{\phi(\sigma)}\frac{\partial}{\partial E}f(E,\mu), \quad B \equiv \frac{1}{\psi(\sigma)}\frac{\partial}{\partial \mu}f(E,\mu), \\ \alpha &\equiv \frac{1}{E}\frac{dE}{d\theta}, \qquad \beta \equiv \frac{1}{\mu}\frac{d\mu}{d\theta}, \qquad \gamma \equiv \frac{1}{L}\frac{dL}{d\theta} \end{aligned}\right\} \tag{5}$$

It is significant that there are no terms inseparably involving both shape factors and thermal properties; as a consequence of this, the complete expression for the effect of temperature on the stiffness of a body, made of a material whose temperature coefficients, α, β, and γ, are known, can be developed empirically without changing the temperature. The dimensionless factors A and B depend only on Poisson's ratio and the generalized shape, while α, β, and γ are familiar thermal properties of the material as such.

It would appear that a body of any fixed shape could be compensated for temperature, provided materials for its construction could be found having such values of α, β, and γ as will make the right hand side of (4) vanish; and, conversely, that a body of any fixed material could be compensated, if its shape could be so modified as to give to A and B values which would make that member vanish.

Simplified expressions for homogeneous isotropic bodies. When the relation

$$\frac{E}{\mu} = 2\,(1+\sigma) \tag{6}$$

characterizing homogeneous isotropic bodies is satisfied, the two factors A and B coalesce into one factor, C, giving

$$\frac{1}{S}\frac{dS}{d\theta} = (1+C)\alpha - C\beta + \gamma \tag{7}$$

in which

$$C \equiv (1+\sigma)\frac{d}{d\sigma}\log\varphi(\sigma) \tag{8}$$

where, by (3)

$$\phi(\sigma) = \frac{S}{LE} \tag{9}$$

The procedure for determining C is simple. Plot the values of $\log \frac{S'}{LE'}$, observed in a series of model experiments, as ordinates against σ as abscissa; S' being any magnitude (for example, the weight needed to give a certain deflection of a spot of light on some arbitrary scale) which is proportional to the true stiffness, S. The value of C, at any part of this curve, will then be $(1 + \sigma)$ times the slope of the curve.

Note from (7) that, when C is positive, the β term has an opposite effect from the α term and may outweigh it. In fact, the condition for temperature compensation is

$$\left.\begin{aligned} \frac{\beta}{\alpha} &= 1 + \frac{1}{C} + \frac{\gamma}{C} \\ &= 1 + \frac{1}{C} \text{ approx.} \end{aligned}\right\} \tag{10}$$

Numerical results in particular cases. For pure stretching or bending, $C = 0$; for pure twisting or shearing, $C = -1$.

For a thin flat circular disc deflected at the center by a so-called concentrated load, while freely supported at the rim, we may take the deflection formula readily available in treatises on elasticity,[6] and, by recasting it into the form of (3), just as if it were the result of model experiments, and then applying (8), obtain the expression

$$\left.\begin{aligned} C &= \frac{2\,(1+\sigma)^2}{(1-\sigma)\,(3+\sigma)} \\ &= 1.5 \text{ for } \sigma = 0.3 \end{aligned}\right\} \tag{11}$$

[6] Thus from Love, *Theory of Elasticity*, 2nd edition, eq. (57), p. 454, by putting $r = 0$ and $h = 0$ and taking the value of D given by eq. (16), p. 443, we find for the stiffness of an infinitely thin disc of radius a and thickness $2\,h$,

$$S = a\,E\,\frac{32\,\pi}{(3+\sigma)\,(1-\sigma)}\left(\frac{h}{a}\right)^3$$

Comparing this expression with our eq. (3), and treating a as the linear dimension L, evidently

$$\varphi\,(\sigma) = \frac{\text{const.}}{(3+\sigma)\,(1-\sigma)}.$$

Differentiating logarithmically, according to (8), immediately gives (11). In the case of a disc clamped at the edge, the expression for C would be $\frac{2\sigma}{1-\sigma}$.

The condition (10) for compensation therefore reduces to $\frac{\beta}{\alpha} = 1.7$.

When β/α exceeds that value, and if, as usual, both α and β are negative, we are led to the paradoxical conclusion that the disc will become stiffer when heated. Nor can the paradox be avoided by supposing that no such materials will be found or that α and β depend on the state of stress—both of which possibilities may in themselves be true—for the variable θ in the differentiation was in fact arbitrary, so that we may restate the conclusion thus: Of two discs having the same Young's modulus, that with the less rigidity is the stiffer.

Note on the proposed experiments. The experiments referred to in footnote (1) have as their ultimate object the development of formulas for the stiffness of corrugated diaphragms. In the course of the experiments it is proposed to determine anew α and β for a series of materials, and thus to test directly the above paradox. A preliminary group of experiments on flat circular discs, conducted at the Bureau of Standards in July with the assistance of H. B. Henrickson, and in which both the increase in hysteresis and the decrease in stiffness with rising temperature were observed, led to the following progression of materials when arranged in descending order of magnitude of the latter effect: soft sheet iron, tempered steel, phosphor-bronze, zinc, aluminum, copper, brass, and German silver. The value of $\frac{1}{S}\frac{dS}{d\theta}$ was about -6 per cent per degree C. for the iron disc, and for German silver it was 0 at small deflections and just perceptibly positive at large deflections; intermediate, but very small and nearly equal, values were found for the intervening materials.

PHYSIOLOGY.—*The importance of vitamines in relation to nutrition in health and disease.*[1] CARL VOEGTLIN, Professor of Pharmacology, United States Public Health Service.

The purpose of my lecture is to give you a brief outline of the most recent phase of the science of nutrition; namely, the impor-

[1] A lecture delivered before the Washington Academy of Sciences, April 28, 1916.

tance of the presence in the diet of man of small quantities of substances essential for the maintenance of health. Until very recently physiology taught that the human diet should meet the following requirements: (1) It should contain an adequate amount of protein, fat, carbohydrate, and inorganic salts; and (2) the daily ration should conform to certain definite requirements in regard to its caloric or fuel value. Once these requirements were met the diet was considered as being physiologically satisfactory.

However, a number of unexplained facts did speak in favor of the assumption that the human diet should also contain some other substances, so-called accessory dietary constituents. For instance, it has been known for some time that scurvy is a disease which occurs in man and certain higher animals when the diet does not contain fresh vegetables or animal foods. Epidemics of scurvy broke out on sailing vessels when the crew was forced to live for several months on such food as canned beef and dried cereals to the complete exclusion of food in the fresh state. During the siege of Paris in the year 1871 part of the population was also deprived of fresh food and an epidemic of scurvy appeared. Scurvy was apparently due to the lack of fresh food in the diet. This conception of the cause of scurvy is supported by the fact that a corresponding change of diet and especially the administration of fresh milk or lemon juice leads to a rapid recovery of most cases affected by this disease. Hence, we might conclude that there exist in fresh food some substances which are essential for the prevention of scurvy. These substances may be designated as *antiscorbutic substances*. As stated previously, they have no direct relation to the other known dietary constituents such as the proteins, carbohydrates, fats, and salts. The chemical composition of the antiscorbutic substance is still unknown, although numerous fruitless attempts aiming at its isolation have been made. All we know about this substance is that it is fairly stable in acid media. This is probably the reason why lemon juice with its high acidity is the classical preparation used in the prevention and treatment of scurvy. For the same reason fresh milk, having a neutral reaction, on being exposed

for a considerable length of time to a temperature exceeding 100°C. loses its antiscorbutic properties and when forming the exclusive diet of children may give rise to infantile scurvy, or Barlow's disease.

Another interesting disease which has been shown to be caused by a diet deficient in the above sense is beri-beri. This disease, being especially prevalent in eastern countries, as Japan and the Philippines, is a disease of the nervous system, and appears in people having lived for several months on a diet which consisted mainly of highly milled (white) rice or wheat. It is interesting to note that this disease is not so apt to appear if the rice forming the diet is not deprived of its outer layers, including the so-called aleurone. Evidently the whole rice grain meets all the requirements of a diet for the prevention of beri-beri. Although beri-beri was known to occur for centuries in the East, many students of this disease were struck by the intimate relation which seemed to exist between the prevalence of the disease and the introduction of highly milled (white) rice. In prisons where the highly polished rice was substituted in the diet of the inmates for the rice of lower milling, epidemics of beri-beri seemed to follow this dietary change. Time does not permit me to go into further detail concerning the many interesting observations which were made in the study of the dietary peculiarities of this disease. It may suffice to say that Eykman, a Dutch investigator, by accident discovered in 1897 that chickens fed exclusively on white rice developed within three to four weeks a disease which he considered as practically identical with human beri-beri. This discovery marked the beginning of the epoch of the systematic study of this disease, and opened up a new field for nutritional studies. By means of chickens or pigeons which had developed symptoms of experimental beri-beri it was possible to test the therapeutic value of food extracts of assumably prophylactic and curative properties. Thus it was soon found that extracts made from rice polishings representing the outer portions of the rice kernel brought about a cure of birds affected with the disease. Efficient extracts were also prepared from

beans, brewers' yeast, and many other raw products. These same extracts were also shown to have some curative value in cases of human beri-beri.

Before entering into the question of the chemical isolation of these curative substances, I should like to call attention to the work of some American investigators which furnished additional evidence as to the importance of some accessory food constituents essential for normal growth. McCollum, Osborne, and Mendel found that a diet of purified protein, fat, carbohydrates, and mineral salts was inadequate for the maintenance of the normal growth of young rats. These discoveries were in contradiction to the previously held conceptions of growth. The diet of these rats was in every respect balanced from the point of view of its content of protein, carbohydrate, fats, and salts, yet normal growth was not observed in rats fed exclusively on this artificial diet. There was obviously something lacking in this diet, which was essential for normal growth.

CHEMICAL ISOLATION OF VITAMINES

Having definitely established the presence in certain foods of unknown accessory food components, it became a matter of considerable importance to determine their chemical nature and physiological action. An enormous amount of energy and time on the part of investigators interested in this question was necessary to obtain our present knowledge of these substances. Preliminary experiments showed that the antiscorbutic and antineuritic substances[2] could be extracted from certain foods by means of water. The antineuritic substances were also found to be soluble in alcohol. By submitting these primary extracts to further chemical purification various workers succeeded in preparing fractions which seemed to be fairly pure and possessed high curative properties. We are especially indebted for this pioneer work to Funk and Suzuki and their collaborators. Funk, in 1912, succeeded in devising a method which led to a product

[2] Antineuritic substances prevent beri-beri and polyneuritis in birds.

of high physiological activity. Two to three milligrams of this substance (that is to say, an exceedingly minute amount) produced a cure of completely paralyzed pigeons sometimes within two to three hours. This substance was obtained in crystalline form, being composed of small needles. The substance seemed to have a definite melting point (233°), and on analysis contained carbon, hydrogen, nitrogen, and oxygen. The properties of the substance in regard to its behavior toward various precipitating agents seemed to warrant the conclusion that it was an organic base; this led Funk to designate this substance as *vitamine*, from *vita* (life) and *amine*, meaning that this substance was an amine essential for life. It is true enough that Funk did not have sufficient evidence to prove that the substance was an amine in the chemical sense, nor did he know whether or not other accessory food substances belonged in the same chemical group. However, he applied the term vitamines to the substances preventing beri-beri and scurvy. These diseases were called *deficiency diseases* or avitaminoses, meaning that the diet which gives rise to these diseases is deficient in certain vitamines. I fully realize the objection which might be, and has been, raised to the use of the term vitamine; at the same time we may, for the present at least, accept this designation, as it is brief and undoubtedly has some truth in it, as these substances are essential for normal life.

The work of Funk and Suzuki has been repeated and somewhat elaborated during the last three years by a number of other investigators. The main difficulty which presented itself in the study of these substances was the fact that with the available methods only small amounts of the relatively pure substances could be obtained from hundreds of pounds of the most suitable raw material, such as yeast and rice polishings. Realizing this difficulty, work was started over a year ago at the Hygienic Laboratory, and somewhat later at the Pellagra Hospital of the U. S. Public Health Service, in search of improved methods for the isolation of vitamines. I am glad to say that the work resulted fairly successfully, although it is by no means completed. For each raw product it seems necessary to make some

modification in the method, in order to obtain the maximum yield. Thus, Dr. Seidell succeeded in removing practically all of the antineuritic vitamine from an active solution of autolyzed yeast filtrate by means of a special preparation of kaolin, or fullers' earth. It was found that the so-called Lloyd's reagent (hydrous aluminium silicate) removes the vitamine from autolyzed brewers' yeast. We must assume that this reaction is based on adsorption, a view which will be referred to later. Vedder and Williams had previously shown that animal charcoal will also remove the antineuritic vitamine from an extract of rice polishings. Furthermore, Funk had observed that kaolin removed the antiscorbutic vitamine from cow's milk. We were able to show quite recently that mastic, a resin, also removes the antineuritic vitamine from an autolyzed yeast solution. Dr. Seidell demonstrated that his preparation of vitamine was fairly stable and inasmuch as it is very easily prepared and at low cost this preparation may be expected to be of value in the treatment of certain deficiency diseases. The preparation is being tested clinically at present. The work along this line at the Pellagra Hospital has also yielded encouraging results. Dr. Sullivan and myself have succeeded in modifying Funk's method in such a way as to give a much better yield and a fairly stable preparation.

I now shall call your attention to some other results obtained by Williams, of the Bureau of Chemistry. Williams prepared some oxypyridines, and on testing these substances on pigeons found that they effected a temporary cure in doses of about 1 mg. This is a most interesting observation. Suzuki and also Funk had previously isolated nicotinic acid from the crude vitamine fraction of rice polishings and yeast. Funk had expressed the opinion that nicotinic acid may be part of the vitamine molecule. It is, therefore, very important that Williams should have discovered the antineuritic properties of some pyridine derivatives, especially as nicotinic acid is also a pyridine derivative. This latter substance, however, has no curative action. Whatever may be the final solution of the chemical constitution of this vitamine, whether the synthetic product has

any chemical relation to the natural vitamine or not, the work just referred to is certainly exceedingly interesting.

CHEMICAL PROPERTIES OF VITAMINES

At present relatively little is known regarding the chemical and physiological properties of vitamines. Some facts, however, have been established. The antineuritic vitamine, for instance, is present in the natural foods, largely in a combined form which is soluble in 90 per cent alcohol, or water. This mother substance can be split into the physiologically highly active substance by acid hydrolysis or autolysis by means of enzymes. Very little is known as to the chemical nature of the mother substance of this beri-beri vitamine. The observations that foods rich in lipoids are also rich in vitamines and the solubility of the mother substance in alcohol might lead to the belief that vitamines enter into the molecule of certain lipoids, an assumption which recent experiments by Sullivan and myself have made highly improbable. The antineuritic substance is probably not in combination with carbohydrates, as the starchy part of cereals seems to be extremely poor in this substance. The probability that certain parts of the protein molecule (nucleic acid) may hold in combination the active substance is still open for consideration.

A fact of fundamental importance is that *vitamines are fairly susceptible to temperatures above 100°C.* A large number of observations made on man and experimental animals show that the prolonged heating of most of the natural foods to a temperature of 120° for one to three hours will destroy most of the physiological activity of the vitamines originally present in these foods. Beef which is submitted to such treatment is found to lead to symptoms of scurvy in man, if forming the exclusive diet together with other food deficient in vitamines.

The vitamines which prevent scurvy and beri-beri seem to be fairly resistant to strong acids. As a matter of fact certain acids seem to prevent the deterioration of vitamines. On the other hand, strong alkalies under certain conditions seem to destroy the physiological activity of vitamines; at least, at higher temperature. The behavior of vitamines to acids and alkalies is of

great importance from a dietary point of view, as we shall see later.

In closing this chapter I should like to raise one more question, namely: Do vitamines occur in colloidal form? Although this question is of a highly technical nature, I do not feel that I can omit giving it some consideration. I have already stated that certain adsorbing agents, such as charcoal, kaolin, and mastic, remove the vitamines from autolyzed yeast solutions, as well as milk. Now we know that these reagents remove substances by means of adsorption, a physico-chemical process characterized by a particular property of the surface of some finely divided substances to condense on it other substances of a similar nature. In order that such a condensation can take place, the adsorbing as well as the adsorbed substance must be in the colloidal state. We have, therefore, good reason to assume that vitamines may occur in the colloidal state. If this should be proven beyond doubt by future investigations, it certainly would help in explaining the remarkable physiological action of vitamines.

PHYSIOLOGICAL ACTION OF VITAMINES

As to the physiological action of vitamines, but very little is known at the present time. Of course, we can easily demonstrate the relief of the paralytic symptoms of polyneuritis in birds by means of vitamines, but we know very little as to the physiological mechanism by which the symptoms are removed. Anybody who has ever observed the effect of an active preparation of vitamine on a completely paralyzed pigeon must be impressed by the marvelous action of these preparations. The animals may look as if on the verge of death, exhibiting a complete paralysis of the voluntary muscles, accompanied with a deep and abnormally slow respiration and a weakened heart action, yet the injection of a few milligrams of active substance will change the picture often completely within three hours. At the end of this time the bird may be seen walking about normally, and greedily eating the food which he had refused before the treatment was initiated. To the pharmacologist the clinical

picture appears to possess all of the earmarks of an intoxication. The rapid recovery might be considered as an antagonistic action of the vitamine to some toxic product contained in the tissues of the animal. This leads me to mention a very striking relation that exists between the beri-beri vitamine (antineuritic) and carbohydrate metabolism. Funk, and Braddon and Cooper observed that for each gram of carbohydrate in the diet there must also be present a certain minimal quantity of vitamine, in order to prevent the occurrence of experimental beri-beri in pigeons. If the carbohydrate or starchy component of the diet is increased, the vitamine content must be increased accordingly. This explains some of the earlier observations that a diet rich in carbohydrates is more apt to give rise to the appearance of beri-beri in man. It is possible that in the absence of a sufficient vitamine content of the body the intermediate products of carbohydrate metabolism may exert a toxic action of some kind which is antagonized by the administration of a sufficient amount of vitamine. So far the natural vitamines were shown to be devoid of any toxic action, if given in moderate doses.

It is of prime importance to state here that *the animal body is not capable of manufacturing the known vitamines from vitamine-free food.* All of the higher animals, including men, receive their vitamine supply directly or indirectly from plants. It is the plant that synthesizes the vitamine, and we obtain our necessary vitamine supply either by eating vegetable food or animal food. Cows store up in their bodies the vitamines which they consume in their fodder; part of it is secreted with the milk, supplying the calf with the necessary vitamines, as well as furnishing a valuable source of vitamine for man. Chickens transfer part of the vitamine content of their cereal food into the eggs they lay. *It is the plant which keeps up the vitamine supply essential for animal life.* The plant is capable of building up the vitamine from simple inorganic compounds, another example of the wonderful synthetic power of plants.

What becomes of the vitamines in the body of animals? This is a very pertinent question, which is not easily answered. Some years ago Funk was able to obtain a small quantity of anti-

neuritic vitamine from dried ox brain. A little later Dr. Towles and myself were able to demonstrate the presence of this substance in crude extracts from the spinal cord which was free from blood and other contaminations and, therefore, represented, to a large extent, nerve cells and nerve fibers. From this it would appear that the antineuritic substance under normal conditions forms an essential part of the nerve cell and fiber and that its presence in nervous tissue in sufficient amounts is essential for the proper function of this organ. When the vitamine content of the nervous tissue is no longer replaced by an adequate supply in the diet, degeneration of the nervous tissue begins. In this connection I also call attention to the fact that lipoids and antineuritic vitamine seem to be distributed in the body in similar proportions. This may be due to the lipoid solubility of the antineuritic vitamine. Another point of importance is that the animal body has the capacity of holding on to its vitamines. If we change the diet of man from one sufficient in vitamines to one deficient or free of vitamine, we find that as a rule it takes several weeks and even months before obvious and well defined symptoms of deficiency diseases appear. One might ask why the body does not react more rapidly to a deficient diet. Apparently the initial vitamine content of the body, which in absolute terms probably amounts to only a few grams in a person weighing 100 pounds, is not easily used up or eliminated together with the excretions. The katabolism of vitamines, if there is such a thing, must be extremely slow. If my statement that vitamines may occur in the colloidal state be correct, and we have seen that a number of facts seem to prove this assumption, it is very likely that certain other body colloids may fix the vitamines in the tissue fluids by means of adsorption. Traube has shown that certain alkaloids with very powerful and prolonged physiological action occur in the form of colloids. The fact that these substances are colloidal may be one of the reasons for their powerful physiological activity, especially as the recent teachings of biochemistry seem to support the view that life itself is largely dependent on the colloidal state of living matter.

Before closing the chapter of the physiological action of vi-

tamines it may be well to point out that recent experiments have demonstrated that normal growth of certain higher animals, and probably also of man, requires a diet which must be sufficient in certain accessory foods or vitamines.

DISTRIBUTION OF VITAMINES IN FOODS

From the practical point of view of human nutrition it is highly desirable to know something of the distribution of vi-

TABLE 1

ANTI-NEURITIC PROPERTIES		ANTI-SCORBUTIC PROPERTIES	
Relatively rich	Relatively poor	Relatively rich	Relatively poor
Brewers' yeast	Sterilized milk	Fresh vegetables	Dried vegetables
Egg yolk	Sterilized meat	Fresh fruits	Dried fruits
Ox heart	Cabbage	Raw milk	Sterilized milk
Milk (fresh)	Turnips	Raw meat	Canned meat
Beef and other fresh meats	Carrots and other vegetables of this type	Cereals, sprouting	Dried cereals
			Pork fat
Fish	Highly milled cereals		Starch
Beans	Starch		Molasses
Peas	Molasses		Corn syrup
Oats	Corn syrup		
Barley			
Wheat			
Corn			
Other cereals			

tamines in the various natural foods. It is important to know roughly whether a certain food like milk or barley is relatively rich or poor in vitamines. Unfortunately we do not possess at the present time a quantitative method for estimating the vitamine content of a given food. The preceding table (Table 1) illustrates the relative vitamine content of foods, beginning with those richest in vitamines. I do not pretend that this table is a very accurate compilation, but in our present state of knowledge it will probably be found of some use in deciding questions as to what constitutes a satisfactory diet from this point of view.

It is fortunate that most people, on account of their dietary habits, live on a mixed diet containing enough of these accessory

foods to prevent an outbreak of scurvy or beri-beri. The average mixed diet is composed of animal food, which, with few exceptions (meat fat), is relatively rich in vitamine, and vegetable food. The latter may contain sufficient vitamines (legumes) or may be relatively deficient in this respect.

FACTORS WHICH TEND TO REDUCE THE VITAMINE CONTENT OF THE DIET

The food supply of the human race is, however, subjected to various changes which may lead to more or less radical changes in the nutritive value and availability of certain foods. The trend of modern civilization, leading to the concentration of the population in large cities away from the source of food production, has strongly influenced the methods of food production and with it also the composition of some foods. This whole question was discussed in an excellent address by Prof. L. B. Mendel before the Second Pan-American Scientific Congress, held in Washington last December. It remains for me only to point out the changes in the food supply which have affected the vitamine content of our diet. We can state without exaggeration that this country has led the world in the introduction on a large scale of modern methods of food production, preservation, and conservation. A number of industries have seen radical changes in modern times. I have only to refer to the development of the canning industry, the packing houses, and the great cereal mills, in order to illustrate this point. These changes, together with increased transportation facilities, have resulted in a wonderful change of our whole economic life. Whereas, people a hundred years ago used to live largely on food raised in this country, the market basket of today is made up of food coming from all parts of the world. The diet of the population of larger cities, and to a lesser extent that of the rural districts, has been subjected to great changes. Nowadays, we are able to purchase all the year around foods which formerly were only available at certain seasons. New foods have appeared on the market. Without these changes in food supply, food produc-

tion, and preservation the development of our modern industrial life would have been utterly impossible, as it is a very essential thing that people should be properly fed. The pertinent question arises: Have these changes in our diet affected its nutritive value favorably or unfavorably? It is perfectly evident that such a question is not answered without a great deal of thorough investigation. All I can say today is that it seems that the diet of a certain proportion of the population may have been materially improved in recent years, leading to a greater variety of dietary components. On the other hand, I firmly believe, as a result of personal observations in a limited portion of the South, that the diet of some Southern people has markedly decreased in nutritive value from the point of view of its vitamine content. This is especially true of people living under rather poor economic conditions. I observed that the poorer people usually were unable to obtain the more expensive foods like beef, or other fresh meat, eggs, and milk, foods which are relatively rich in vitamines. Their diet was largely composed of cereal products, pork fat, carbohydrates in the form of molasses or corn syrup, and a few canned products. During the summer, and less so in the winter, fresh vegetables also were procured, some from their own gardens. The following table is an example of the yearly food supply of a family of cotton mill workers in Spartanburg County, South Carolina.

This dietary record is representative of a fairly large percentage of the cotton mill workers of this section of the South. It should be emphasized that the wheat flour which is used by these people is highly milled (patent) and forms perhaps the most important staple article of the diet. The diet as a whole must be considered as deficient in antineuritic vitamines, with the exception of the beans, which this family raised in their garden. During the winter time the cereal products, namely, wheat flour, corn meal, and grits, and pork fat (fatback) form the bulk of the diet. It is evident, therefore, that under these conditions it is important that the vitamine content of the cereal products should be sufficient, in order to prevent the consumption of a deficient diet. From the point of view of public health it is of considerable

importance that the bread supplied for human consumption should contain the highest possible nutritive value.

TABLE 2

EXAMPLE OF YEARLY FOOD SUPPLY OF A FAMILY OF COTTON MILL WORKERS

	COST	AMOUNT	PROTEIN	CARBOHYDRATE	FAT	CALORIES
		gram	*gram*	*gram*	*gram*	
Baking powder	$4.35	9,222				
Beans (dried)	.55	3,624	816	2,160	66	12,840
Blackberries (canned)	.25	1,410	18	153	14	837
Bread (wheat)	.50	3,670	390	1,770	43	9,260
Butter	2.85	6,114	61		5,165	49,103
Candy	.50	2,265		2,172		8,922
Cheese	3.45	7,224	2,139		2,774	30,799
Chicken (one)	.25	1,132	154		139	1,937
Corn (canned)	.20	250	28	198	12	838
Corn meal	10.25	184,824	17,001	139,352	3,504	675,240
Crackers	3.00	3,660	358	2,729	329	15,617
Cream of wheat	.45	2,400	264	1,830	33	8,907
Dried peaches	.25	1,812	119	1,607	17	7,163
Fat salt pork	22.41	58,663	2,944		72,962	690,498
Jelly	1.25	3,240	40	1,935		8,115
Lard, Compound	10.30	43,486			43,486	405,120
Watermelon	.75	3,000	9	137		585
Oatmeal	.15	588	98	389	43	1,964
Peanuts	.05	126	32	31	48	716
Porkside	1.12	4,303	408		2,650	26,410
Potatoes, Irish	9.00	224,235	4,933	41,269	224	190,575
Salmon (canned)	3.95	19,756	4,112		2,341	39,864
Sardines (canned)	.25	475	95		85	1,220
Soda	.50	3,971				
Sour kraut (canned)	.40	3,716	64	140	18	1,000
Sugar	5.95	37,824		37,824		155,304
Syrup (corn)	.25	2,730		1,932		7,608
Syrup (cane)	1.80	16,308		11,298		46,440
Tomatoes (canned)	1.45	9,888	118	394	17	2,228
Wheat flour	31.35	429,897	48,987	325,102	4,298	1,575,340

From all of the available data one may conclude that the nutritive value of bread made from corn or wheat remained much the same from the time of the early settlers to about 1880. During this long period bread was prepared from wheat flour or corn meal and salt, with or without addition of other ingredi-

ents, such as fresh milk, buttermilk, molasses, et cetera. The wheat flour or corn meal was obtained by simply crushing the whole grain between stones, by various means, to the desired degree of fineness. The resulting flour or corn meal, from which the coarser particles of bran were partly sifted out, was then used for baking bread. Accordingly, the bread contained practically all of the nutritive elements of the whole grain. During the last fifty years, however, radical changes have taken place, with the tendency of reducing considerably the vitamine content of bread.

The introduction of the roller mill system into the United States in 1878 represents probably the most important change in this direction. By means of the roller process it was made possible to separate more or less the various parts of the kernel, namely, the germ, or embryo, the bran, and the endosperm, or starchy part. The latter represents the bulk of the fine (patent) flour, which, on account of its white appearance, appealed to the housewife as an assumably purer product. Accordingly the germ and bran were largely discarded as human foods. While it is quite true that the highly milled products (wheat flour, corn meal, corn flour, and grits) obtained by the roller process are far superior to whole wheat flour and the old-fashioned corn meal, as far as the keeping qualities are concerned, at the same time this modern process deprives the finished products of some of their vitamine content, an assumption which has been amply verified in some recent work by Myers and myself. These substances are located in the intact kernel in the outer layers (aleurone layer) and probably also in the germ.

Fowl, the classical experimental animal for the physiological estimation of the vitamine content of foods, will live in perfect health for many months on an exclusive diet of wheat, corn, whole wheat flour, or so-called water ground corn meal. If these animals are fed, however, on highly milled products, they will die within a month or two of polyneuritis, a disease very similar to beri-beri. There seems, therefore, to exist a perfect analogy between the well known relation of the polishing of rice and its nutritive value, and the milling of wheat and corn and the

nutritive value of wheat flour and corn meal. As stated previously, numerous observations have demonstrated the fact that if the diet of people is largely made up of highly polished rice and is otherwise deficient in vitamines, beri-beri will make its appearance; whereas, if undermilled rice is substituted for the highly milled variety the disease is not so likely to break out. Little[3] reports an epidemic of beri-beri among the fishermen of Newfoundland who lived mainly on bread made from highly milled wheat flour.

From these considerations it would appear that a simple method for the determination of the vitamine content of cereal products would be of great value. Unfortunately it is still impossible to base such a method on the direct isolation of these substances from the natural foods. The determination of the total phosphorus content of these products, however, seems to give a fairly accurate index of the relative amounts of vitamines present. While phosphorus does not enter into the vitamine molecule, the distribution of phosphorus and vitamines within the grain run practically parallel. Fraser and Stanton, on the basis of a large number of observations and analyses, came to the conclusion that rice containing less than 0.4 per cent of P_2O_5 is deficient in vitamines. Myers and myself have used this method in order to correlate the vitamine content of wheat and corn products as found by animal experimentation with that of the quantitative estimation of the P_2O_5 content of these same products. Without going into detail it was found that in the case of these cereals the same relation exists between P_2O_5 and vitamine content as in the case of rice. (See Table 3.)

We believe that the determination of the P_2O_5 index will be found of value in all cereal products, except the so-called "self-rising flours." These latter products contain baking powders which often are composed of phosphates. As the label of these flours always indicates whether baking powder has been added, it will be an easy matter to discard such flours for this purpose.

I now should like to call attention to another factor involved

[3] LITTLE. Journ. Am. Med. Assoc., 58: 2029. 1912.

in the reduction of the vitamine content of corn bread. This concerns the *use of baking soda in the preparation of bread.* Simultaneously with the introduction of highly milled corn meal it was found that this product, when mixed with salt and water, did not yield a bread of the same lightness as the old-fashioned meal. Housekeepers, therefore, began to resort to artificial leavening. Baking soda (sodium bicarbonate) became very popular among

TABLE 3

SUMMARY OF EXPERIMENTS

	PER CENT P_2O_5 IN DRY FOOD	NUMBER OF DAYS REQUIRED FOR APPEARANCE OF POLYNEURITIS IN FOWL FED EXCLUSIVELY ON THIS FOOD
Wheat bread, made from highly milled flour	0.114	20–32 days
"Patent" wheat flour	0.20–0.25	20–40 days
"Whole wheat" flour	0.61	Remained well
"Graham" flour	0.86	Remained well
Whole wheat	1.120	No symptoms developed
Corn grits (highly milled)	0.210	30 days
Corn meal (highly milled)	0.30	35 days
Corn meal (old fashioned rock ground)	0.659	Remained well
Corn meal (rock ground)	0.772	Remained well
Corn germ	2.816	Remained well
Corn whole	0.760	Remained well

The various methods for the estimation of P_2O_5 yield different results. The method used in this work was described in Hygienic Laboratory Bulletin No. 103, and is considered as being very satisfactory for comparative analyses. Explanation of terms used: (1) "Undermilled cereal products," cereals retaining a large share of the aleurone layers and germ; (2) "highly milled cereal products," products that have been deprived to a great extent of the above mentioned parts of the germ. These terms have been in common usage in the scientific literature and are, therefore, adopted in this paper.

the housekeepers. This preparation is used very extensively for this purpose in South Carolina, where I had an opportunity of studying its uses in cooking. Bread made by means of baking soda has often a distinctly alkaline taste. In order to prepare bread in this way corn meal is mixed with water or sweet milk, and fat, to which baking soda has been added. The resulting mush is baked in the oven. The high temperature in the oven lib-

erates carbon dioxide from the baking soda (sodium bicarbonate) and the latter is transformed into sodium carbonate, a strong alkali. The evolution of CO_2 causes the bread to rise. Recent experiments by Sullivan and myself have clearly demonstrated the destructive action of alkalies, under certain conditions, on vitamines. These substances lose their physiological activity when exposed to alkalies, this being especially true at higher temperature. Corn bread made from old-fashioned (whole) corn meal, sweet milk, and soda, when forming the exclusive diet of chickens leads to symptoms of polyneuritis, whereas, corn bread prepared

TABLE 4

LABORATORY NUMBERS OF ANIMALS	NUMBER OF DAYS REQUIRED FOR APPEARANCE OF POLYNEURITIS AFTER FEEDING WAS BEGUN
31	13
32	14
33	27
34	13
35	22
36	14
37	19
38	21
39	18
40	16
	17 days (average)

from corn meal, sweet milk, and salt (NaCl) does not give rise to any symptoms and fowls seem to live in perfect health. Chickens which have developed polyneuritis on the corn bread made with sweet milk and soda are cured by the administration of vitamines prepared from various foods. *Hence, we may conclude that corn bread prepared by means of baking soda, without the addition of butter-milk, or substances of an acid character* (cream of tartar), *is deficient in antineuritic vitamines and that this deficiency is due to the destructive action of the alkali* (baking soda) *on the vitamines which were originally contained in these foods.*

The preceding table (Table 4) illustrates the destructive action of baking soda on the vitamine content of corn bread. Ten

chickens were fed on corn bread of the following composition: 600 gm. of corn meal, 800 cc. of sweet milk, and 10 gm. of baking soda. Chickens fed on corn bread made with 600 gm. of corn meal, 800 cc. of sweet milk and 10 gm. sodium chloride did not subsequently exhibit at any time symptoms of polyneuritis.[4]

It should be strongly emphasized, however, that the old-fashioned way of combining baking soda with butter-milk in the preparation of bread is a perfectly harmless procedure, provided that sufficient butter-milk is added to neutralize fully the alkalinity of the baking soda. The label of the brand of baking soda in use in Spartanburg County, South Carolina, clearly states that butter-milk or tartaric acid should be added in order to obtain the best results. The prevalent use in that section of the country of baking soda *without butter-milk or tartaric acid* seems to be due to the lack of knowledge on the part of the housewives, as well as to the fact that it is often very difficult to obtain butter-milk.

We do not mean to imply that the use of baking soda will always lead to an injurious action on the health of persons eating bread prepared by this method, although such bread is undoubtedly deficient in vitamines. However, when the other dietary components, outside of corn bread, are also deficient in vitamines, the consumption of corn bread made with baking soda accentuates this dietary deficiency and may lead to an impairment of health. The same statement holds true in the case of highly milled cereals.

A few words about the *effect of food preservation on vitamines* may not be out of place here. Various methods have been in use for this purpose. Simple drying at ordinary temperature of such food as legumes, cereals, etc., has been in vogue for many centuries. In the absence of moisture food decay does not take place. Drying, however, seems to reduce the content of foods in antiscorbutic vitamines. The antineuritic vitamine, on the

[4] One chicken of this series, however, developed after a very long time symptoms of paralysis which were relieved by the administration of vitamine.

other hand, is only slightly affected by this treatment.[5] Salting and smoking food is also commonly resorted to. Little is known as to the effect of these last mentioned methods of preservation on the vitamine content. Another method of food preservation which has assumed immense proportions within the last 50 years is the canning of food. The process of canning was discovered in the time of Napoleon the first, who offered a prize to the scientists of his country for a method of preserving fresh foods. Appert received the prize, as he was able to show that food exposed for some time to the temperature of boiling water and kept from contact with the air could be stored for a considerable time without danger of decay. This process was used to a limited extent in the period immediately following its discovery, but the credit belongs to this country for having put it on a large scale, until nowadays nearly everybody consumes part of his diet in the form of canned foods. It seems important, therefore, to determine whether or not canning of food deprives the food of some of its vitamine content. Experiments having this idea in view have been made by myself and others on a small scale, but it is altogether too early to draw any definite conclusions. Thus, several statements can be found in the literature pointing to the destructive action of the canning on the antineuritic vitamine present in fresh meat and fresh milk. On the other hand, I have been able to show that canned peas and beans seem to retain a considerable amount of antineuritic vitamine. Such questions should be given considerable attention, keeping in mind, however, that the benefits derived from the fact that canned foods are available for human nutrition are very considerable. This statement applies equally well to the milling of cereals. While it is of prime importance to preserve the full nutritive value of foods, at the same time it is imperative that we also consider the great benefit which our modern methods of food production and food preservation have yielded. Any deficiencies in these methods from the point of view of the

[5] Holst and Froelich in 1907 succeeded in producing scurvy in guinea pigs by means of an exclusive diet of dry cereals.

preservation of vitamines which might possibly be discovered in the future should be removed if possible without disturbing the normal continuation of these valuable industries.

OUTLOOK

Looking back over the history of the discovery of the accessory foods and especially the vitamines, we at once realize that it has opened up a new field of investigation, undreamed of a relatively short time ago. Fundamental problems in physiology, pharmacology, and pathology are awaiting the worker interested in this field. The purely scientific, as well as the practical, aspects of this field should stimulate research, which will require a small army of workers in order that rapid progress be made. It is of great importance that vitamine preparations should become available for the practicing physician for the treatment of deficiency diseases. It is quite possible that a number of indefinite complaints and symptoms of adults and infants may be due to a partially deficient diet and would be benefited by the administration of vitamines. It is not always necessary that the full picture of a deficiency disease make its appearance. Such vague symptoms as loss of appetite and general weakness might very well, in some instances, be due to a deficient diet. In passing, it should also be stated that the scientific and practical problems of stock-raising will probably be very greatly benefited by researches on the effect of vitamines on the growth of animals and the composition and nutritive value of cows' milk. Efforts should be made to make use of certain industrial wastes rich in vitamines, such as brewers' yeast, rice polishings, etc. If certain reports are correct, Germany at the present time is fully aware of the great nutritive value of brewers' yeast, inasmuch as this raw product is now used in that country for human nutrition.

In conclusion I should like to emphasize an old truth quoted by Langworthy to the effect that "Each country and each epoch has its own food problems." It is up to us to solve them.

ABSTRACTS

Authors of scientific papers are requested to see that abstracts, preferably prepared and signed by themselves, are forwarded promptly to the editors. Each of the scientific bureaus in Washington has a representative authorized to forward such material to this journal and abstracts of official publications should be transmitted through the representative of the bureau in which they originate. The abstracts should conform in length and general style to those appearing in this issue.

METEOROLOGY.—*Weather forecasting in the United States.* ALFRED J. HENRY and others. Weather Bureau Publication No. 583. Pp. 370, with 199 charts and diagrams. 1916. (For sale by Superintendent of Documents, Washington, D. C.)

It is a matter of common knowledge that although weather forecasts have been made in the United States for upwards of forty years, scarcely anything has been written to explain in more or less detail the processes by which weather forecasts are made. This volume is the result of an attempt to put on record the rules and considerations which have been found useful by experienced forecasters of the Weather Bureau. The volume has been prepared primarily as an aid to beginners in the art, and presupposes some acquaintance on the part of the reader with graphic methods of presenting weather data. It is not for general distribution.

Preliminary chapters upon the theoretical aspects of the problem of atmospheric motions have been contributed by C. F. Marvin and Wm. J. Humphreys.

The relation of atmospheric pressure distribution and of certain well known barometric configurations to subsequent weather is discussed in three chapters by Alfred J. Henry. The well marked phenomena of the weather, such as cold waves, frosts, high winds, fog, snow, sleet, and thunderstorms, are discussed in four chapters; cold waves and frosts are discussed by Henry J. Cox; high winds, by Edward H. Bowie; fog, snow, and sleet, by H. C. Frankenfield.

Three chapters, devoted to the routine forecasts of wind and weather, are contributed by the district forecasters for the five forecast districts of the country, and, finally, a chapter on long range forecasts is presented by E. H. Bowie. A bibliography concludes the work.

A. J. H.

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